Neutron Streaming Through Labyrinth from a Cyclotron Room

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Introduction

Neutron streaming through a labyrinth in accelerator facilities is one of the most important problem for shielding design and further difficult problem among the shielding calculations. A computer code based on the Boltzman transport equation, is generally not applicable to the neutron streaming, because of the complicated geometry of the labyrinth and the long CPU time.

Simple analytical formulas have been, therefore, used for the neutron streaming calculation in the shielding design.[1-3] Validity of these simple formulas have been examined by a few experiments[3-5], however, the measurement in the actual accelerator facilities is few and is restricted to dose equivalent measurement.

We measured both energy spectrum and dose equivalent of neutrons streamed through a labyrinth in the cyclotron facilities, in order to investigate the energy distribution of streamed neutrons and to examine the validity of the simple formulas.

Experiment

We made the neutron measurements in the AVF Cyclotron room and in the labyrinth connected to the room at the Cyclotron and Radioisotope Center, Tohoku University (CYRIC). Figure 1 shows the plan view of the experimental geometry and the neutron detection points in numbers.

A 35-MeV proton beam extracted from the cyclotron, was stopped on the copper beam stopper in the cyclotron room, in order to produce high energy neutrons. Neutrons which were reflected many times on the concrete surface in the cyclotron room and the labyrinth, were measured with the NE-213 liquid scintillation counter and the multi-moderator spectrometer with a ^{3}He counter, i.e., Bonner Ball. The measured data were unfolded to the neutron energy spectrum by the FERDOU code[6] for NE-213 and by the SAND-II code[7] for Bonner Ball. A direct dose equivalent measurement was also made with the dose equivalent counter, in order to compare with the dose equivalent obtained by multiplying the measured energy spectrum and the flux-to-dose conversion factor given by ICRP-51.[8]

Simple formula

Three kinds of simple formulas, Shin's code[1,9], Nakamura & Uwamino's formula[2] and Tesch's formula[3], were examined. Shin's code can calculate the neutron energy spectra in the target room and in the labyrinth with the albedo method. Nakamura & Uwamino's formula can calculate the neutron dose equivalent in the target room and in the labyrinth, which is based on a inverse square law. Tesch's formula can calculate the neutron dose equivalent in the labyrinth, which is based on a inverse square law and an exponential function.

Results and discussion

The comparison of the spectra given by Bonner Ball and Shin's code are shown in Fig. 2, and the comparison of measured and calculated dose equivalent data are shown in Fig. 3.

In Fig. 2, the high energy neutrons above 100 keV are dominant at the entrance of the labyrinth, but thermal neutrons become dominant with the depth of the labyrinth. The comparison between experimental and calculated spectra shows good agreement at position 1 in the cyclotron room, but the absolute values of calculated spectra become larger than those of measured spectra with penetrating the labyrinth, nevertheless the relative spectral shape between experiment and calculation are close together.

In Fig. 3, the dose equivalent data given by Bonner Ball and Rem Counter agree each other at all positions, except for the cyclotron room (position 1). The discrepancy at the position 1 may be come from the inaccurate measurement of very weak proton beam current (about several nA), in order to keep neutron intensity relatively low.

On the way of the second leg, there is a step in the experimental value which comes from the shielding of the iron door with 8 mm thickness.

The calculation by Nakamura & Uwamino's formula and Tesch's formula underestimated the dose at the position 3 of the first leg in comparison with the experiment. This can be explained as follows. The first leg is not a straight leg, but goes downwards to the position 3 by steps, and then the neutrons are incident slantly to the leg, which causes more leaked neutrons than those in the normal incidence to the straight leg. These formulas, however, can not take account of the slant incidence. In the second leg, these formulas estimate the dose with the safe side and Nakamura & Uwamino's formula is closer to the experiment than Tesch's formula.

Shin's code overestimated the dose at all positions but the slope of the curve is relatively similar to the experiment and Nakamura & Uwamino's formula. We considered that the overestimation of the dose equivalent values was caused by the neutron shielding effect of the equipment around the beam stopper and the overestimation of the albedo data[10] for the target room.

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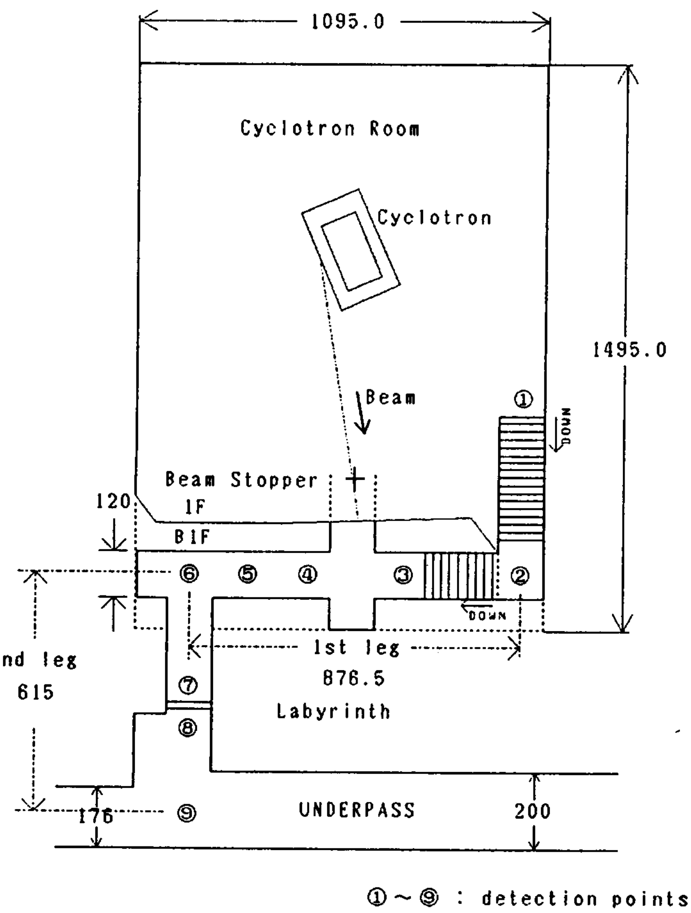

Fig. 1. Plan view of the cyclotron room and the labyrinth.

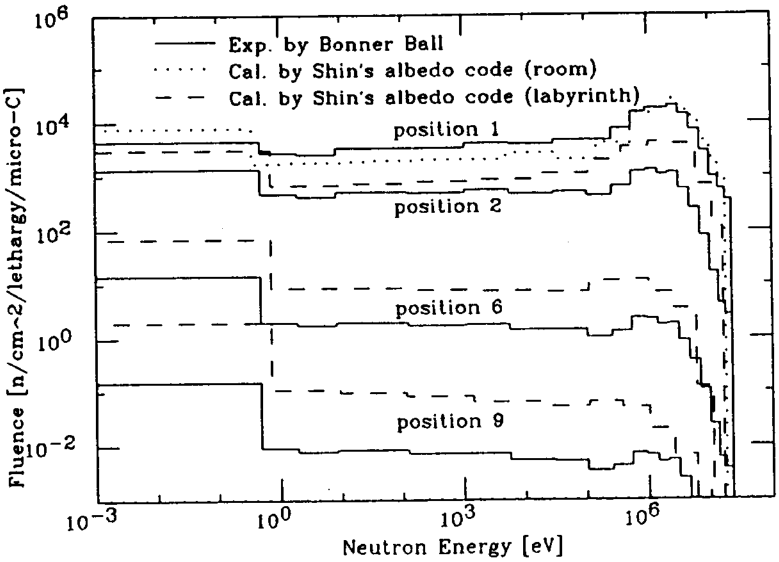

Fig. 2. Comparison of neutron energy spectra between experiment and calculation.

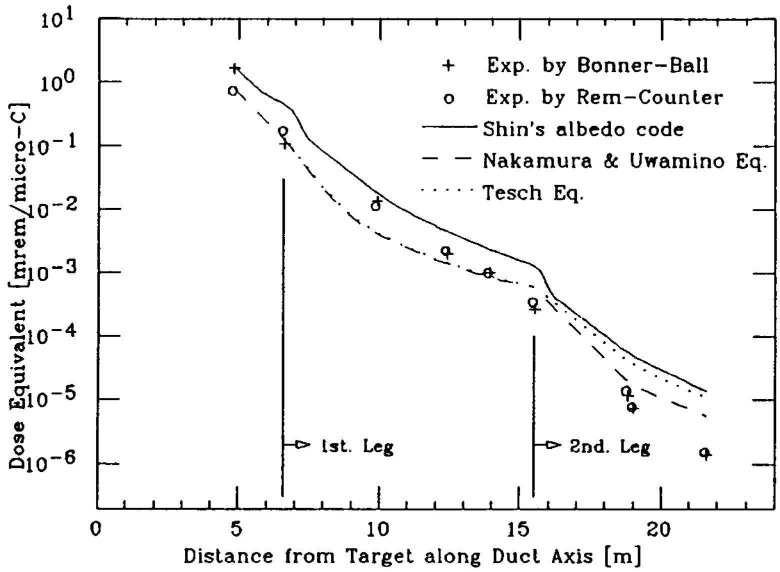

Fig. 3. Comparison of dose equivalent between different methods.